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BIM-based information model for the provision of the demand-oriented facility management services janitorial cleaning

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ABSTRACT

Background and aim – Facility management (FM) refers to multidisciplinary activities pertaining to performance-based or results-based delivery. Although results-based delivery provides economic benefits, missing definitions of the demands on executing facility services (FS) present a challenge to contractors. Existing sensor-based systems for identifying the demand of FS require building-relevant information. Building information modeling (BIM) offers the possibility of creating FM-relevant information as early as the building planning phase. While not all data from the planning phase are relevant for executing FS, we aim to present a BIM-based information model for the sensor-based determination of executing FS.

Methods / Methodology – This research focuses on the FS of janitorial cleaning. First, an analysis of contract specifications is conducted to identify demand orientation in tendering and awarding processes. Next, the information required for the execution of FS is defined, structured, and constituted as an information model. The model includes interfaces for implementing a sensor-based determination of executing FS.

Results – The result is an information model containing all the required information to provide effective FS. The linking of the individual information structures of the model forms the basis of using sensor-based methods to determine the demands of FS demand-based-delivery.

Practical or social implications – Information on the demand and location of a service provision is necessary to determine the requirements of FS as well as to commission, perform, and document activities. Different stakeholders can use the developed information model. By the model, the required information is already defined in the planning phase of a building, which minimizes the risk of information loss.

Type of paper – Research paper (full).

KEYWORDS
BIM, demand-oriented FM, soft facility service delivery, janitorial cleaning.

INTRODUCTION
At 44%, occupancy costs are the most significant cost component in the life cycle of a building (Bogenstätter, 2008; Litau, 2015). Infrastructural facility management (FM) encompasses multidisciplinary soft and hard facility services (FS). Hard facility services relate to technical aspects such as building services or plant and machinery. Soft facility services (SFS) pertain to the management of human needs in the use of a building, such as janitorial cleaning or space management. Infrastructural FM accounts for the second-largest revenue share of SFS. In 2020, the FM industry generated revenues of €44.7 billion, of which 59% (€26.37 billion) was attributable to infrastructural FM (Lünendonk &

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Hossenfelder GmbH, 2021). However, infrastructural FM is also the most significant cost driver in the management of buildings; depending on the type of building, 50% to 73% of costs in infrastructural FM are attributable to cleaning (Rotermund, 2016). In FM, SFS can be delivered in a performance-based or output-based manner, which is also known as demand-oriented FS delivery. In performance-based delivery, the main concern is the actual activity process and the quality of service delivery. Service delivery is based on defined process specifications, whereby the need for service delivery is assessed at particular intervals of service delivery, such as weekly or daily. Service descriptions include the performance and functional requirements stipulated in service level agreements (SLA) (Hirschner et al., 2018). While delivering demand-oriented SFS, the focus is not on the performance process but on the achieved result that was previously agreed upon between the contracting parties (Gondring et al., 2018). The performance of SFS requires building-relevant information that occurs at different phases of a building life cycle. Collaboration amongst project stakeholders in FM for exchanging required information is one of the biggest challenges in the architecture, engineering, and construction (AEC) industry. By supporting this collaboration, building information modeling (BIM) can advance FM activities handled by different stakeholders (Wills et al., 2018).

The successive digitalization of the AEC industry in Germany, particularly in BIM and sensor technologies, represents opportunities for delivering SFS in a more efficient way. BIM is a rapidly evolving method in the AEC industry (Fauth et al., 2019) and has been gradually implemented in infrastructure projects in Germany since 2020 (BMVI, 2015). Through BIM, information is theoretically utilizable from the planning phase to the use phase of buildings. In addition to BIM, sensor technologies and the Internet of Things (IoT) are recognizable trends in the FM industry (Al Dakheel et al., 2020; Fialho et al., 2020). In practice, IoT and sensor technologies are used in sub-areas of FM, such as energy management, occupancy management, or janitorial cleaning (Jaspers et al., 2018). Sensor technologies offer the possibility to record condition parameters. The monitoring, interpretation, and associated information generation of building environments form the basis for FS delivery (Dibley et al., 2011). The most significant drawback to FM-based sensor technologies is their realization via niche products programmed and installed by software manufacturers for specific customer needs (Pärn et al., 2017; Zhang et al., 2015). Software manufacturers neglect to provide scientific elaborations concerning the determination of needs for demand-oriented SFS delivery. While recent research endeavors focus on sensor-based FM, the integration of BIM for demand-oriented FS is lacking. Moreover, the focus of using sensor technologies in FM is energy management and maintenance management, which considers individual sub-areas of FM, but not service-oriented activities of IFM (Atta et al., 2020; Edirisinghe et al., 2020). We seek to demonstrate and link the information required for demand-oriented SFS delivery which must be known at the planning phase of buildings. First, we quantitatively analyze FM contract specifications of janitorial cleaning with regard to the status of demand orientation. Next, the information required for the demand-oriented FS delivery is defined, categorized, structured, and constituted as an information model. Simulations are conducted to test whether the information model comprises the correct values of information for determining demands and delivering SFS. We conclude with a discussion of the results and with an outlook on potential future research directions.

LITERATURE STUDY

BIM in FM

To date, BIM is primarily used in the planning phase and construction phase of buildings (Succar, 2009), whereas the usage of BIM in FM is rare, despite known advantages (Bartels, 2020; Bender et al., 2018). BIM in FM is applicable to SFS, such as space management support (occupancy planning), contract management (transfer of tenant data into the BIM model), realizing FM sustainability targets according to "German Facility Management Association" (GEFMA) guideline 160 "Sustainability in Facility

Management" (Wills et al., 2018), occupational health and safety for FM staff (Wetzel et al., 2018), hard facility services such as maintenance and repair (GEFMA, 2019b; Hu et al., 2018), the planning of remodeling and new construction measures, and simulations for energy optimization (GEFMA, 2019b). To use BIM in FM, requirements for FS delivery must be considered as early as the planning phase of buildings (GEFMA, 2019b). Therefore, the requirements must be integrated into the Employers Information Requirements (EIR). The EIR aim to ensure that the correct quality and quantity of information is available in the correct place simultaneously (GEFMA, 2019b; VDI Verein Deutscher Ingenieure, 2020). Defining detailed requirements of FM in the EIR avoids conflicts between stakeholders (Becerik-Gerber et al., 2012; Kassem et al., 2015).

Contributing to the problems cited by Teicholz (2013) for the low level of BIM in FM are a lack of information required for FS delivery as well as the poor quality and quantity of information (Bartels, 2020; Giel et al., 2016). However, internationally, BIM in FM is limited to less than 1% of all new and as-built buildings (GEFMA 926). Reasons for the limited use are a lack of standards and the unrecognized benefits of a life-cycle approach in companies (CAFM Ring e.V., 2017). Moreover, data relevant for demand-oriented FS delivery are not known in the planning phase of buildings but must be provided by the client. Paradoxically, the client to perform FS is not assigned until the use phase of buildings. In practice, FM receives a large amount of irrelevant information for the actual FS delivery (Kassem et al., 2015). As an example, the cleaning of floor surfaces is mentioned: in addition to the relevant information of the surface material, in practice, other attributes are supplied, such as the thickness of the covering and the fabric of the underlying structure, e.g., screed, and the ceiling. Unnecessary information leads to extra work in terms of management and structuring (Dias et al., 2020). The inconsistency between information supply and information demand represents another barrier in integrating BIM in FM. Although BIM enables greater information for FM, this information is not necessarily represented in FM-compliant semantic formats (GEFMA, 2019b). According to the recommendation of GEFMA, the concepts for the provision of services should be prepared within the construction phase in the life cycle phase (LCP) 3 of a building and commissioned in LCP 6, which is the maintenance and usage phase of a building (GEFMA, 2013b). However, the requirements of service providers known from practice cannot be integrated into the building planning process since the development of concepts, commissioning of service providers, and handover of documents occurs at a later stage. While BIM is primarily used for hard FS, research endeavors on BIM for SFS are rare.

Sensor technologies in FM

In FM, sensor technologies and the IoT represent a significant trend in further developments of digital building operations: A study of FM companies from 2019 shows that 36% of the participants name sensor technologies and IoT (34%) as a significant trend in digital building operations. Other trends are service robots (26%), e-commerce (24%), Augmented Reality (23%), machine learning (22%), and Artificial Intelligence (21%) (Hossenfelder et al., 2020). By IoT, building users, facilities, components, and FS can be (physically) connected by sensor technologies to communicate with each other (Jaspers et al., 2018). Furthermore, the IoT enables FM stakeholders to create knowledge-based sensor data to link and retrieve this data on demand via intelligent systems such as information platforms (Atta & Talamo, 2020; Jaspers et al., 2018). In FM, IoT describes the current behavior of building subsystems, building users, or user experience. Furthermore, IoT can be used to monitor the climate, energy and resource consumption, building condition (from a structural engineering point of view), or the demand for space (Jaspers et al., 2018). FM-based sensor technologies lead to improvements in FM, e.g., in the area of space management or maintenance and repair planning (Gomes-Jauregui et al., 2019; Parn et al., 2019). Energy management and maintenance management constitute the services mainly used in BIM- and FM-based sensor technologies (Al Dakheel et al., 2020; Atta & Talamo, 2020; Edirisinghe & Woo, 2020). The research field on the integrated approach of BIM and sensor technologies in FM considers individual sub-areas of FM but not demand-oriented SFS delivery. Full-scale research and integration approaches for using BIM and sensor technologies in FM with all the associated task areas, especially in operational FM, are only available in rudimentary form.

RESEARCH METHODS

Before identifying and defining information required for SFS, demand orientation in current tendering and awarding processes has been investigated. Therefore, we have analyzed the specification of services, contract documents, and SLA of tendering processes (n=43) for janitorial cleaning. The analyzed documents of public and private clients cover a total area of 84,664.96 sqm cleaning area. The keywords, and any combination thereof, that were searched were “as needed,” “if required,” “as required,” “as necessary,” “as and when required,” “if necessary,” “according to requirements,” “as the need arises,” “demand-oriented,” “just in time cleaning,” “dependent on requirements,” or “just in time delivery.” Next, the required information for executing the SFS janitorial cleaning had to be identified and constituted as an information model. The constitution of a model for identifying the determinants of demands is a multi-stage process. To identify the general information required to deliver the SFS janitorial cleaning, a comprehensive literature review was conducted to gain an overview of the required information on demand-oriented FS delivery. To this end, the review included an in-depth survey of guidelines, standards, and best-practice approaches. Moreover, the previously analyzed documents of current tendering and awards processes have been investigated with regard to information required for fulfilling janitorial cleaning. In particular, the GEFMA guideline is applied in European countries such as Austria and Switzerland. While in Europe, the cleaning industry is subject to legal regulations, in the US, for example, no licenses or regulations are required exclusive to this industry. In the USA, various municipal guidelines and occupational health and safety regulations are required, including those relating to the use and safe storage of cleaning chemicals and compounds. (Lang, 2021). Table 1 shows the investigated guidelines and standards classified by institutions. Guidelines by the GEFMA and “German Social Accident Insurance” (DGUV) are only available in German. The authors have listed the original guideline titles and the translation in the table below. To ensure that the information identified is generally valid for different building types, analyzed documents were examined according to building and room use types per DIN 32835-2.

Table 1 Reviewed guidelines and standards.

Institution	Guidelines and standards
DIN	DIN 32736:200-08: Building Management – Definitions and scope of services. DIN 32736:200-08-Beiblatt 1: Building Management – Definitions and scope of services – Comparisons of services. DIN 32835-1:2007-01: Building Management – Definitions and scope of services – Comparisons of services. DIN 32835-2:2007-02: Technical product documentation – Facility management documentation – Part 2: Building occupancy documentation DIN EN 15221-5-5:2011: Facility Management – Part 5: Guidance on Facility Management processes; German version EN 15221-5:2011 DIN EN 13549: Cleaning services – Basic requirements and recommendations for quality measuring systems; German version EN 13549:2001 DIN EN 13549 (2001-08-00): Cleaning services – Basic requirements and recommendations for quality measuring systems; German version
GEFMA	GEFMA 100-1: Facility Management: Grundlagen (Facility Management: Basics) GEFMA 100-2: Facility Management: Leistungsspektrum (Facility Management: Range of services) GEFMA 198-1: Dokumentation im Facility Management (Documentation in Facility Management)

	GEFMA 198-2: Dokumentation im Facility Management – Einzeldokumente (Dokumentenliste) (Documentation in Facility Management) – Single documents GEFMA 922-01: Übersicht zu Daten und Dokumenten im Lebenszyklus einer Immobilie (Overview of data and documents in the life cycle of a building) GEFMA 470: Austausch digitaler Daten im FM (Digital data exchange in FM) GEFMA 924: Datenmodell, Kataloge und Ordnungsrahmen für das FM (Data model, catalogs, and regulatory framework for FM)
Other	DGUV-R 209, DGUV Regel 101-019: Regeln für den Umgang mit Reinigungs- und Pflegemitteln (Rules for handling cleaning and care products) DGUV-I 659: DGUV-Informationen – Gebäudereinigungsarbeiten (Information – Building cleaning services) (German Statutory Accident Insurance [GSAI])-Information: DGUV Regel 101-605: Branche Gebäudereinigung (Branch cleaning services) BGR 209 DGUV Regel 101-018 (2001-10-00): BG-Regel - Umgang mit Reinigungs- und Pflegemitteln (Handling cleaning and care products)

Once the required information had been identified, the results were categorized according to content context. Subsequently, the categorized information was structured by its content and divided into process information, building information, and sensor information. In order to determine demands based on information, the structuring of information is established on the modeling of a relational database. The applicability of the developed BIM model is tested virtually as a simulation which enables different scenarios of the utilization phase to be run through in a theoretical building. The building information represents a non-real office building in IFC format, edited in the BIM software Autodesk Revit 2021. The considered maintenance area is 408.48 sqm. The information structures were exported from the Autodesk software and imported into the CAFM software. In the simulation, 64 virtual sensors are used that count up measured values, e.g., people counters and garbage can levels. Fifteen sensors are used, counting down measured values, e.g., levels in soap and hygiene dispensers. The simulated factors are weather, number of people in the building, and dust content of indoor air.

RESULTS

Demand orientation in janitor cleaning

The analysis of current tendering and award process documents has shown that explicit definitions of the demands of service are missing. As shown in Figure 1, only 72% of the analyzed documents mention demand-based keywords. Further examination of these documents has revealed that only 6% of them include a description of demands. However, the mentioned definitions indicate that the recognition of a demand to execute FS is the contractor's responsibility. None of the examined documents contains objectively traceable and measurable metrics for when demand exists.

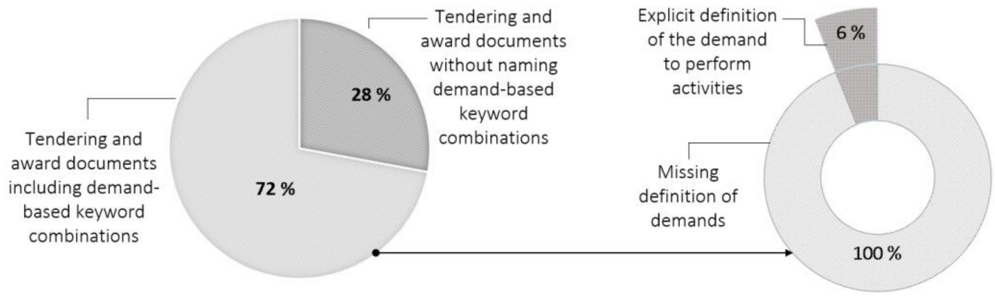

Figure 1 Demand-orientation within tendering and awards documents of janitorial cleaning.

Relevant information for providing the facility service of janitor cleaning

The literature reviewed in this paper shows that SFS are performed on elements, areas, and facilities. To provide a sufficient quantity of information for FM performance from the planning phase to the operational phase, particularly in regard to the SFS of janitorial cleaning, the following information is required: cleaning interval, surface material, elements to be cleaned, spatial placement of the elements, work method (e.g., sanitary module or wet area), quantity and size of elements, care instructions, job description, and building accessibility. Next, the defined information must be categorized. The categorization of information according to its context is based on the types of information defined by GEFMA, which result in such categories as "as-built," "process," and "other information" (GEFMA, 2013a). Table 2 shows the identified information categorized according to its content context.

Table 2 Categorization of required information for FS performances.

Type of information	Content	Justification
As-built information	Buildings and furnishing (surface material, spatial placement, elements, quantity, size)	In the use phase of buildings, the construction only changes due to external interventions, e.g., a planned refurbishment, modernization, or remodeling.
Order information (process information)	Service provider (contact, payment terms)	Information on SFS contract awarding, such as the service provider, only changes due to an intervention by the FM, e.g., the commissioning of a new contractor.
Status information (process information)	Demand / need	The current state of elements is subject to changes even without explicitly planned external influences. For example, the degree of soiling of floor surfaces is changed by foot traffic and weather influences.
Information on consumption (process information)	Demand / need	Media consumption and fill levels (e.g., soap) in buildings in use change continuously and are therefore categorized as dynamic.
Other information	Activity/task (care instruction, execution, cleaning area, cleaning interval/schedule)	Information relevant for the delivery of SFS that are agreed in SLA only changes due to an intervention by the FM, for instance.

In summary, three types of information are identified that are relevant for the delivery of SFS:

1. Information about the building, equipment, spatial allocation, surfaces, and materials, which do not change without external influence. In the following, this information is referred to as "building information."
2. Information describing the performance of services, such as, activities, method of performing the activity, times, contractor, and instructions for performing the activity. This information is referred to as "process information."
3. Information concerning the need for activity execution. Although the interval is static, it is classified as dynamic concerning the demand orientation. Since sensor technologies determine the demand for fulfilling FS delivery, this information is referred to in the following as "sensor information."

The information relevant for providing a service is now categorized but is not interconnected. Therefore, the categorized information is structured into meaningful entities with attributes. First, building information and process information are structured, followed by the structuring of sensor information.

Structuring of building information

First, we will structure the above identified and categorized building information for executing SFS. Categorizing a building demands a unique identification and location (GEFMA, 2019a). While an identification number (ID) enables a unique identification, the address of a building specifies its location. Since a building commonly consists of floors that include rooms, floors and rooms represent the required information for spatial placement. A unique number and name identify both. The execution of SFS demands an area, which is the size of a room. Rooms, in turn, contain elements where the execution of activities takes place. Elements include all objects located in a building, i.e., equipment and furnishings, components, and installations. All elements in a building have at least one surface. An example is a wall whose surface is wallpaper. However, some elements consist of multiple surfaces and surface materials, such as a chair with casters of plastic, a frame of metal, and a seat of linen fabric. In order to structure the content of the multitude of elements in a building, elements are typified in BIM. The assignment of an element type to each element, such as furniture, technology, sanitary equipment, or walls, is already used in applying open data exchange formats such as Industry Foundation Classes. The FS delivery is implemented via room groups or component groups. Therefore, grouping elements allows the delivery of FS to occur flexibly with regard to individual elements or several related elements, enabling demand-oriented service delivery. Moreover, janitorial cleaning contains care instructions with details on cleaning. Other FS also contain instructions that must be considered when performing activities, such as the safety warnings for the maintenance and operation of elevators and escalators (DIN, 2017). Since activities are performed on elements, the instructions also refer to these.

For realization in a database, the information defined above must be combined into meaningful entities and attributes. The authors choose primary keys in IDs for unique identification in a database to identify the entities.

Structuring of process information

Next, we will structure information concerning the SFS delivery performance, referred to as “process information.” An SFS delivery consists of a job, an order, and a client. Each job consists of various activities. For instance, the delivery of janitorial cleaning includes activities such as vacuuming, dusting, or mopping. Service delivery comprises the commissioning, the execution, and the documentation of activities. In practice, various activities, such as filling soap dispensers, emptying dust bins, and wiping floors, can be combined into one order. Therefore, an order includes a clear description of the activities required, the address of the client, and a textual description of the activity required. The execution time is a parameter for remuneration and control over the performance. For demand-oriented SFS delivery, the possibility of direct notification to the skilled worker instead of the company contact should exist. The type of notification can take various forms, such as SMS or e-mail. Analogous to the structuring of building information, separate entities and attributes of the process information are interconnected.

Structuring of sensor information

For delivering SFS on demand instead of in defined fixed intervals, sensor technologies conduct the recognition of demands. For this purpose, information that influences SFS delivery is to be derived from the activities of an SFS. Exemplarily, the demand of cleaning floors depends on the information “degree of soiling.” Sensors that are mounted on elements within rooms record the level of soiling. An IP address and a unique name identify the sensor. Sensors are integrated into a network and communicate via protocols. Moreover, the sensors for recognizing demands are located on and in elements that belong to rooms. To secure sensors against unauthorized access, the definition of usernames and passwords are possible. Therefore, we introduce entity sensors, whose attributes are ID sensor, sensor name, IP, username, password, room, and measured variable.

Total modeling

The defined information structures of building information, process information, and sensor information are to be placed in an overall taxonomy, as shown in Figure 2.

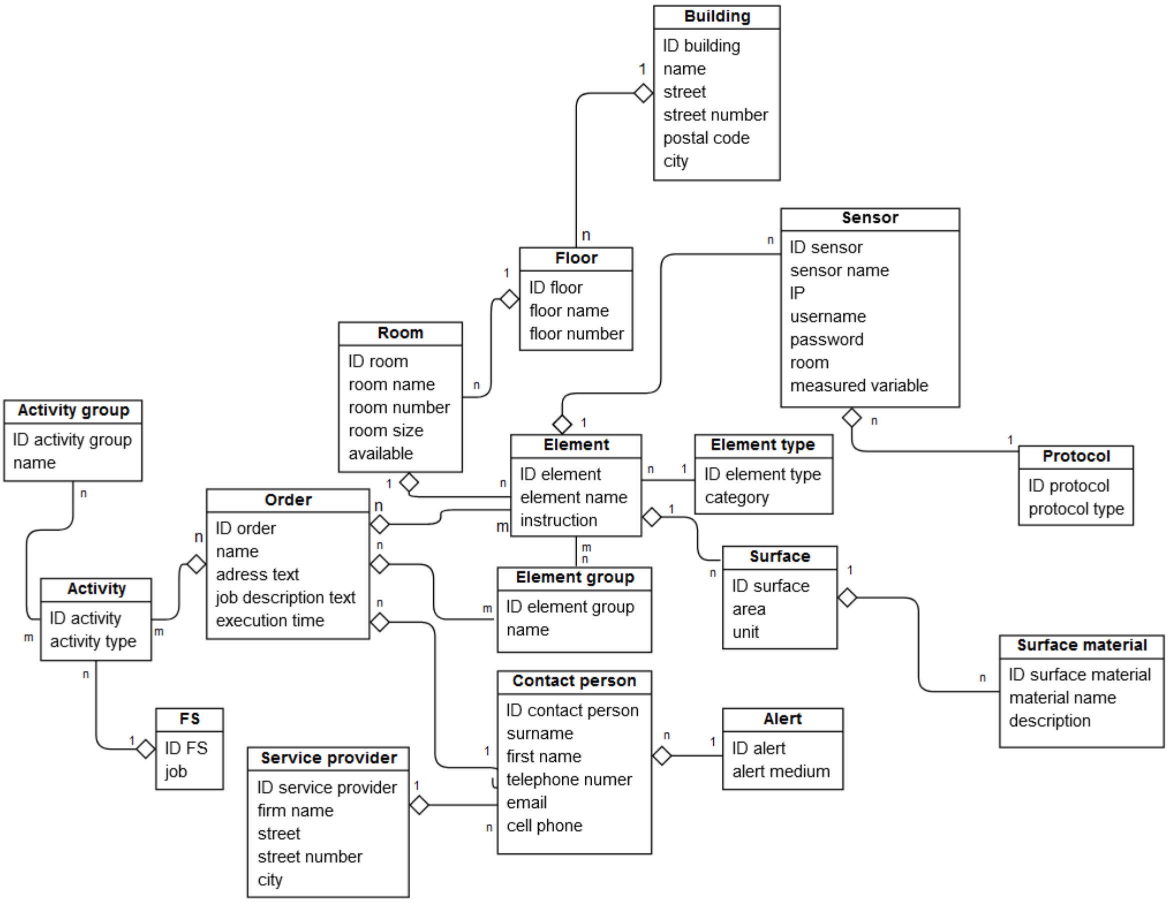

Figure 2 Total modeling.

As the analysis on standards, guidelines, and current tender documents indicates, activities are performed on elements. To deliver different activities with similar demands simultaneously, activity parameters, activity groups, and elements must be affiliated with each other. Therefore, these entity types are related to "job." Each of the relations is an m:n relation because many jobs can contain many elements, activities, and activity groups. The sensors used for recording demands are mounted on elements or integrated into ceilings, walls, exterior facades, or as pressure sensors in moving screens.

The developed information model is created analogously to the diagrams in a relational database, as they are mainly used in FM. All information has been exchanged from BIM software to FM databases.

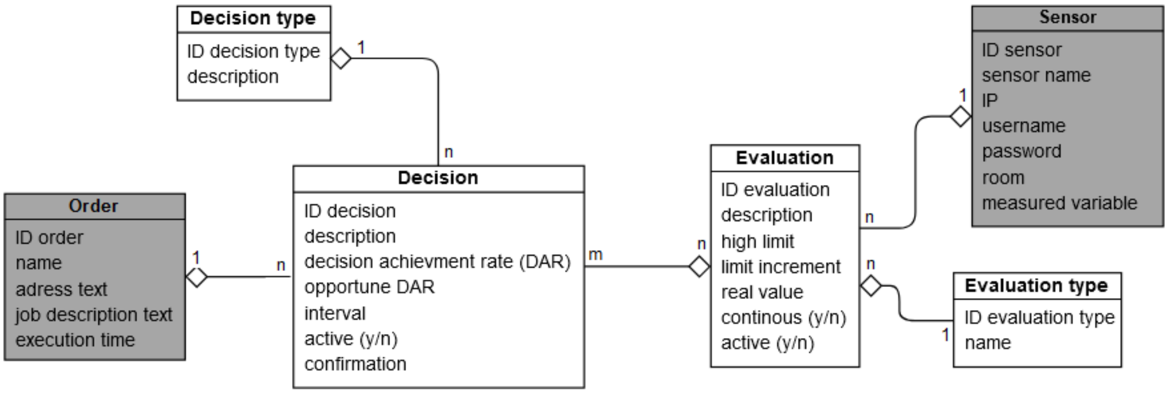

Figure 3 Information structures for demand determination.

The databases moreover consist of algorithms and rules. The algorithms access the measurement values of the sensors and recognize the demand of delivering SFS mathematically. The model user can chose between different types of decisions for carrying out activities within one job. The information structures for making a decision and awarding an order are shown in Figure 3. Grey-colored entities represent the interfaces to the above shown total BIM-based information model.

In order to demonstrate the potential of demand-driven SFS delivery, simulations were performed using the developed information model and algorithms for demand determination. In the simulation period under consideration, 306 orders of janitorial cleaning were triggered based on a daily fixture-based service provision at 6pm (performance-based cleaning) and 259 orders based on BIM-model-based service provision. Figure 4 compares a partially amount of orders for each type of service provision.

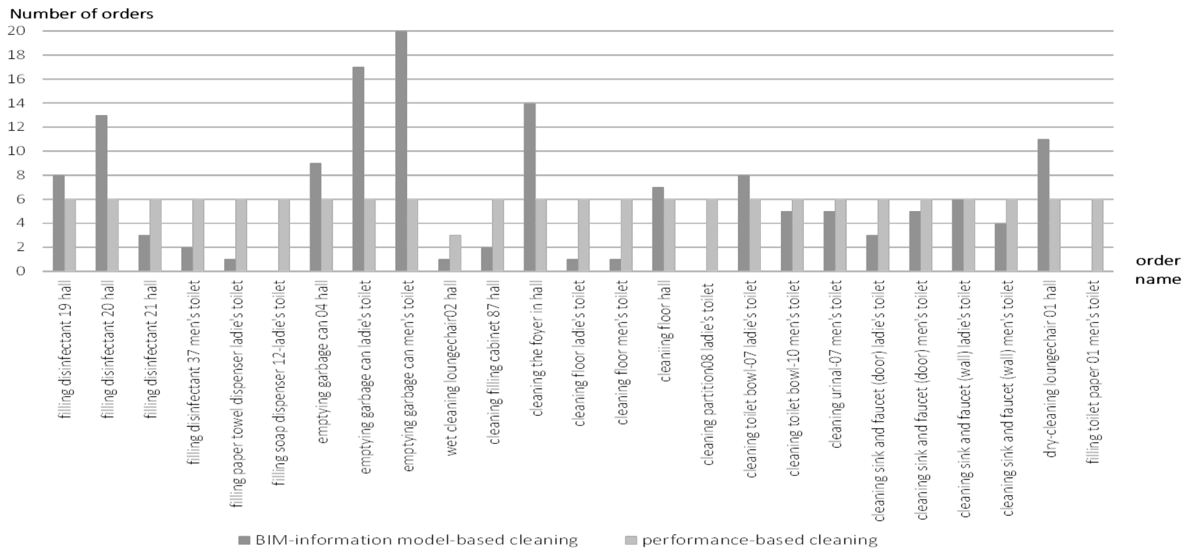

Figure 4 Comparison BIM-model-based and performance-based service provision.

If the pure processing time of the assigned activities is summed up on the basis of performance indicators of janitorial cleaning, 16.36 hours are provided for the BIM-information model-based cleaning and 20.58 hours for the performance-based cleaning, which results in a saving of 20.5%.

DISCUSSION AND CONCLUSION

The analysis of current tendering and award documents has revealed a lack of definitions concerning when SFS must be performed. Missing definitions of current demands for SFS execution lead to dissatisfaction on both parties to the contract. Demand-driven service delivery requires the service provider to identify demands to deliver contractually defined results. Manual needs assessments based on visual inspections are subjective and do not provide a fully quantifiable needs assessment. Furthermore, determining a demand for SFS delivery results in cost increases to the contractor when personnel is required to capture the need through visual inspections. BIM only proves advantageous if FM requirements are communicated between all project participants as early as the planning phase. Not all information that arises in the planning and construction phase is required for executing individual FS, such as janitorial cleaning. Therefore, only the required information must be communicated at the beginning of the project. Existing BIM use cases consider the outcome-oriented service delivery of SFS in FM. BIM use cases already represent sensor-based approaches for determining requirements of hard FS. However, the execution of demand-oriented SFS, which significantly influences the management costs, has not been considered in these use cases.

We have investigated information requirements for delivering SFS in a demand-oriented manner. A quantitative analysis of guidelines, standards, and current tendering documents has been conducted to define information required for delivering SFS. The identified information has been categorized, structured, and linked to a BIM-based information model. Simulations have demonstrated that using the model delivers the correct quantity of information for recognizing demands, ordering, and delivering facility services. As a result, the developed model that consists of FM-relevant attributes shall be presented as Asset Information Requirements and included in the BIM project documentation. The results of this paper relate to recent research on BIM use cases such as "Cleaning Management" of the University of Wuppertal (Helmus et al., 2020). However, the information model developed in this paper aims to create an information model of sensor-based demand-oriented SFS delivery.

Our research has several limitations. First, the SFS of janitorial cleaning represents only one of many infrastructural soft facility services. Therefore, it might be a valuable investment to create analogous BIM-based information models for several demand-oriented SFS. Second, the developed BIM-information model is based on Industry Foundation Classes and must be tested for functionality against other open data exchange formats. Next, the validation of the demand assessment for the delivery of FS based on simulations was carried out. A worthwhile task for future research is to verify the applicability of the BIM information model in actual buildings. Lastly, the scope of this paper did not permit a detailed description of the algorithms and rules used for recognizing the demand of SFS.

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